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Probabilistic Fracture Mechanics for Reactor Pressure Vessels – Lessons Learned

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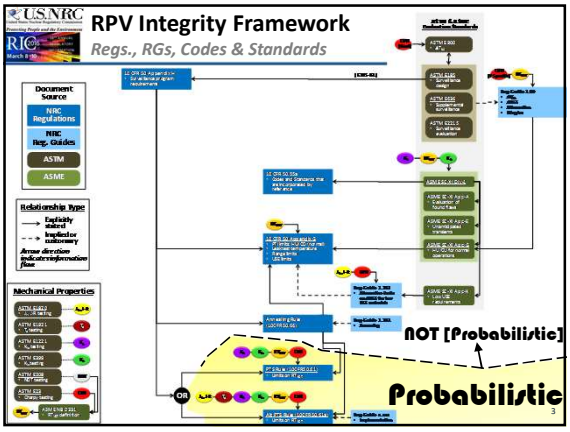
Outline

- **Reactor pressure vessel (RPV) structural integrity framework**
- **"Deterministic" *vs*. "Probabilistic" approaches … similarities & differences**
- **Lessons learned – the alternate pressurized thermal shock (PTS) rule (10 CFR 50.61a)**

RPV Integrity Framework

Regs., RGs, Codes & Standards



Ensuring RPV Integrity

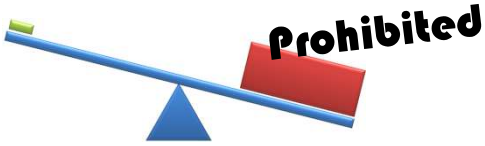
Deterministic vs. Probabilistic Approaches

Fracture Toughness > Fracture Driving Force

Ensuring RPV Integrity

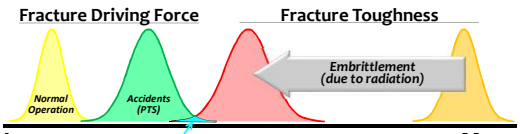
Deterministic vs. Probabilistic Approaches

Fracture Toughness < Fracture Driving Force



Ensuring RPV Integrity

Deterministic vs. Probabilistic Approaches



10 CFR 50 Appendix A, GDC 31
"… the probability of rapidly propagating fracture is minimized."

"The NRC does not regulate to zero risk"

Ensuring RPV Integrity

Deterministic vs. Probabilistic Approaches

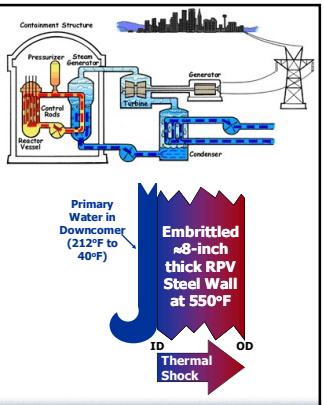
Similarities

- Both treat uncertainty mathematically
  - **Deterministic**: *bounds* uncertainty
  - **Probabilistic**: *quantifies* uncertainty
- Probabilistic models have deterministic parts when full information is lacking:
  - Conservative models
  - Bounding inputs
  - And so on …

Differences

- Form of answer
  - **Deterministic**: "Failed" or "Not Failed"
  - **Probabilistic**: A failure probability
- The decision maker
  - **Deterministic**: The engineering analyst (because *"failure"* is unacceptable)
  - **Probabilistic**: Many people (because some *failure probability* can be accepted)

What is PTS?



Primary Side Break

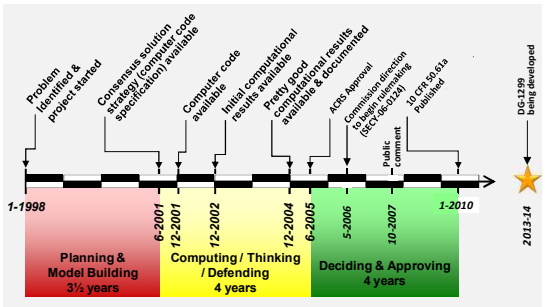
- **Inventory (water & steam) lost through the break is replaced by colder (40-70 °F) water held in external tanks**

Secondary Side Break

- **Loss of pressurization in the secondary leaves water boiling (212 °F) at atmospheric pressure**
- **Primary side inventory just across the heat exchanger also approaches 212 °F**
- **Natural circulation in primary draws colder water into downcomer**

Pressurized Thermal Shock

Alternate Rule (10 CFR 50.61a) Development Timeline, Lesson #1

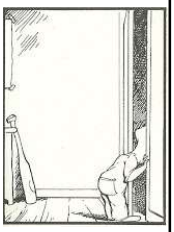


Pressurized Thermal Shock

Alternate Rule (10 CFR 50.61a) Development Timeline, Lesson #1

Why does this take such a long time?

- **An integrated assessment**
  - More complex than "usual," so
  - Involves more technical specialties than "usual," so
  - More engineers needed to develop the model & critique the result
- **An integrated assessment requires**
  - Technical specialists, *and*
  - Connectivity experts
- **Based on a different paradigm than "usual"**
  - Usually each technical specialty gets its own margin
    - Obvious coverage
    - Comfortably conservative
  - PFM uses best-estimate models
    - Margin addressed at the end
    - Margin expressed on failure probability, not on technical specialists' variables



Pressurized Thermal Shock

Lesson #2: Communication & Understanding is Vital

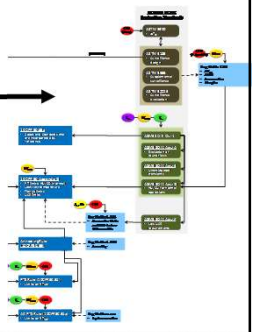
- **Need a means to communicate model & results at any level of granularity**
  - For overview presentations

*Successful

Pressurized Thermal Shock

Lesson #2: Communication & Understanding is Vital

- **Need a means to communicate model & results at any level of granularity**
  - For overview presentations
  - For technical specialists
- **Benefits of diagrams**
  - Reveal the assumptions of, and gaps in, long-accepted deterministic practices
  - Promotes systematic and thorough engineering
  - Promotes discussion & drives consensus across disciplines
  - Used during all phases of project
    - At beginning: to build models
    - At end: to critique models

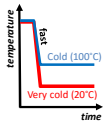


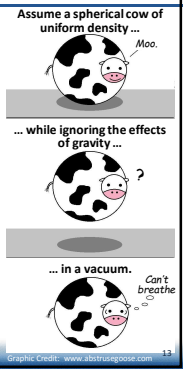
Pressurized Thermal Shock

Lesson #3: Assumptions Drive Real Actions

- **Engineers make assumptions**
  - Expedient & practical *("simplify the problem")*
  - Conservative
  - Gets the job done
- **The assumptions impact the answer, & the answer drives actions**

PTS Example

MSLB Model	Model Result	Action
	2000 (10CFR50.61a), Accurate MSLB insignificant contributor to PTS risk	Nothing needed
	1984 (10CFR50.61), Conservative MSLB dominant contributor to PTS risk	Significant operator training to avoid MSLB events

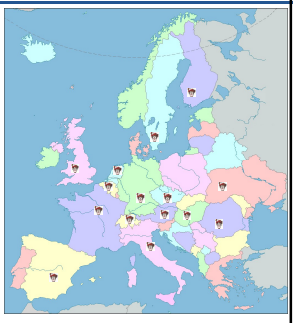


Graphic Credit: www.abstrusegoose.com

A Closing Thought

From a European Friend

*"I know that when a licensee uses a probabilistic analysis to make a safety case they have exhausted all other options." **



* **Likely so (because why would one do something more complicated than needed?), but this does not make the answer wrong.**